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THE MONIST

THE MODERN THEORY OF ENERGETICS.*

SINCE the middle of the last century when the comprehensive significance of the law of the conservation of energy became generally acknowledged, the conviction has also developed that this law must serve as the foundation of the natural sciences, above all of physics. The realization of this thought, however, though in itself quite obvious, has been retarded by inertia of every kind so that even to-day there is hardly a text-book on physics which seriously undertakes to work out a presentation of the several laws and relations strictly in this sense; and this requirement has been met even in a less degree in other neighboring realms of science.

So closed the nineteenth century, and its greatest discovery was not yet granted the practical recognition and significance to which it justly lays claim. In 1896 at a conference of naturalists in Luebeck I gave a hint of this obligation and necessity in a lecture on the "Triumph of Scientific Materialism" which attracted considerable attention, but could not alter the general condition of affairs. For this it would be necessary to show by means of a survey over the whole realm of science that the concept and the laws of energy really possess the power to unify and to give light which has been ascribed to them, since they direct the attention of investigators to the real problems and exclude pseudo-problems from the discussion. This was done in 1902 in my "Lectures on Natural Philosophy" (*Vorlesungen über Naturphilosophie*).

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* Translated from the German in the opening number of the *Rivista di Scienza* by Lydia Gillingham Robinson.

Since that time the significance of the theory of energy, or energetics, for the general world-conception has come to the consciousness of increasingly wider circles. At any rate most philosophers and philosophizing naturalists to-day occupy themselves mainly with attempts to refute energetics. That these attempts are constantly renewed is an involuntary evidence that each opponent of energetics considers the onslaughts of the rest as not sufficiently deadly, and hence believes that his own attacks are needed to finish the work. More important than these attempts which are occasioned at regular intervals by mistaken conceptions of the problem, is the increasing acceptance which the fundamental ideas of energetics have found among the workers of science. The biological sciences especially begin to recognize a very efficient means of progress in the treatment of their problems which is furnished by energetics.

On the other hand, energetics coincides with that movement which has originated on philosophical ground and which pursues very similar ends under the name of "pragmatism" or "humanism." This at least makes it plain that energetics corresponds to definite requirements of the day.

In the following pages I shall not, therefore, undertake to write anew an outline of energetics itself; for this I must refer to the above mentioned writings. On the contrary, I have set myself the task to help those who have already taken the opportunity to familiarize themselves with the main issue, in finding their way among the manifold new paths of thought. In the above-mentioned objections I have found sign-posts pointing out the most serious obstacles in this direction. Indeed, this has been a real, although perhaps not contemplated, service which I have derived from those attacks. They have shown me where the hitherto customary modes of thought most impede a conversion to the newer view.

Great discoveries in natural science always bring in their train a far-reaching reform of general philosophical conceptions and modes of thought. One can easily point out the influence of the discoveries of Galileo, Kepler and Newton in the philosophy of the eighteenth and nineteenth centuries. Indeed this influence acts like a process of diffusion, that is to say, at first only those special branches of science are affected which lie nearest, and the farther away their domain, the later the influence of the new thought will be felt. Herein consists a very definite and characteristic difference between the times when the influence of a new thought is felt in the domain of the special sciences and in that of philosophy. The effect produced on philosophy is frequently not apparent until the special science has so far come to an understanding with the new conceptions that they become self-evident, that is, we no longer give them any thought.

But this reciprocal action becomes peculiarly complicated because of the following circumstance. Except in periods of unusual philosophical activity the specialist in science troubles himself but little with the elements of the universal or philosophical conceptions which he employs for the purpose of classifying his several data; and this is because they apparently do not essentially enter into the consideration of the latter. So specialized science is not only slow to adopt the corresponding thought-formations of contemporary philosophy, but even thinks little of changing them again forthwith to correspond to the modifications of philosophical conceptions. Therefore it remains as far behind philosophy as philosophy commonly remains behind science, whence arises a twofold delay in the philosophical components of the special sciences, which of course does not appear in technical treatises but in the introductions to text-books. So for example the venerated primary and secondary qualities of John Locke still continue to maintain rather an undisturbed existence as a philosophical pensioner in text-books on physics. In spite of the Dalton law, according to which each gas in a compound of different gases exhibits the same properties and reaction as if it alone were present in that space, although thus, in other words, the gases are said to actually penetrate each other undisturbed and uninfluenced, no text-book neglects to teach in its first chapter the impenetrability of matter as an absolutely universal principle.

These remarkable conditions must be borne in mind if one would judge correctly the position of energetics in the science and philosophy of to-day. The idea of matter as the real substratum of all natural phenomena and as endowed with weight and mass, has arisen from the paramount influence of Newton's theory of gravitation, to which at the end of the eighteenth century was added the law of the conservation of weight even in the case of chemical processes. Side by side with ponderable matter earlier science had quietly accepted imponderable matter as well, such as fire, electricity, etc. Even Lavoisier who was the first to point out clearly the remarkable significance of relations of weight in the determination of chemical processes, showed the influence of tradition by including heat and light in his table of chemical elements although he knew that they did not possess measurable weight. However, in the nineteenth century these antiquated notions disappeared completely, and the dualism of matter and force developed, in which upon matter devolved the function of substance in the Aristotelian sense while the rôle of attribute (*Accidenz*) was assigned to force. In this way matter became the only real thing in phenomena, and the imponderables, heat. light and electricity, attained thereby a peculiarly false position.

This feeling is most clearly expressed by Julius Robert Mayer in his fundamental treatise of 1842, "Remarks on the Forces of Inanimate Nature" (*Bemerkungen über die Kräfte der unbelebten Natur*). Mayer can not agree to the idea that forces should so come and go, now here and now gone, while only inert, lifeless matter should possess the advantage of indestructible duration; and so with conscious intent he seeks for a similar expression for that other imponderable essence which would establish its claim to a law of indestructibility. "There are two divisions of causes in nature between which no connecting link can be found experimentally. One division consists of the causes to which belong the attributes of ponderability and impenetrability, — forms of matter; the other, the causes which lack these attributes,—forces which because of their characteristic negative attribute are called also imponderables. Accordingly forces are indestructible, mutable, imponderable objects."

A desire for unity is the essential point in these declarations which as the first public presentation of Mayer's ideas contain the most direct expression of his thought. Even though Mayer can ascertain no connecting link between these two divisions he cannot make up his mind to treat them as quantities of an entirely distinct character as was customary in his time, and therefore he brings into prominence their agreements with a distinctness which even to-day acts like a thrust on those naturalists who stand for the older conception. Even to-day there are many who object to looking at force (or to give it its modern name, energy) as an *object,* and up to the very latest times remarks can be heard or read to the effect that matter is of course a reality, but that energy is not real but only thought. These propositions, to be sure, would prove even more than was intended. They prove that in the minds of their advocates energy is not even *thought,* for if they had considered the relation of energy to the concept of reality, they would not have made such propositions.

It is well known that Mayer greatly hindered the right appreciation of his ideas by setting himself in opposition to the customary nomenclature. There is positively no doubt that Mayer knew perfectly well that his "force" was called "work" in contemporary mechanics, (at least in one particular case; in another, to be sure, it was also called "force" in the expression "living force" or "momentum"). To those who would unjustly accuse him of a mistake in this particular he makes this pertinent remark: "As far as force is concerned, the first question is not what sort of a thing 'force' is, but rather, what thing it is that we wish to call 'force.' " If we will substitute the word "energy," which is now in general use, in the above-mentioned definition of Mayer, it will read "energies are indestructible, mutable, imponderable objects."

Here, indeed, we have the conception which has been valid for more than half a century since the discovery of the law of the conservation of energy. In this connection in addition to the just mentioned conceptions of forces the word "object" has been heard but very little. While the conservation of matter (which does not actually exist at all, for only weight and mass are conserved while everything else pertaining to "matter" is changeable) stands for something natural and self-evident so that it is usually proclaimed to be a necessity of thought, the conservation of energy appears surprising, remarkable,—at any rate as something which bespeaks our astonishment and admiration.

This is the point at which modern energetics enters. First it would be necessary to make clear the thingishness or reality of energy, in connection with Mayer's train of thought, so that old respectable Matter ought not feel ashamed in the company of energy in spite of the latter's dubious imponderability. In the second place, however, the assumption which Mayer made without close scrutiny, that the two were absolutely separated and without any connecting link, required a more exact investigation. The conclusion, as may already be inferred from this, is a complete reversal of the relations heretofore considered valid. While energy becomes clear and more confirmed as a reality, the claims of matter disappear and matter is left without any rights except those of tradition. Matter must not only tolerate energy on an equality as the progressive text-books of the natural sciences to-day demand, but it must even yield its place unconditionally and withdraw as a superannuated dowager upon her reservation where, surrounded by a court of adherents of the past, she may await her approaching dissolution.

We observe here in Mayer a phenomenon which in spite of its singularity belongs to the most common in the psychology of investigators. It consists in the fact that the investigator does not pursue to the end the path which he himself discovered and trod. He regularly leaves in his work a remnant of the same false or redundant conception which he undertook to remove. We have just seen in the case of Lavoisier how in spite of his discovery of the far-reaching significance of gravity for the interpretation of chemical processes, especially for the determination of elements, he included in his table of elements, the essences light and heat which are without weight.

In the same way Copernicus set aside the epicycloid theory for the motion of the earth in relation to the sun while he considered the earth to be in motion and the sun stationary. Meanwhile he still clung to the epicycloids for the rest of the planets.* In the same way Mayer has at last recognized that ponderability is not an essential mark of the reality of a thing since he has verified *imponderable realities.* But his critique has not gone far enough to ask whether ponderability is to be assigned as important a rôle as the older theory had given it. He granted it this rôle without attempting its justification and by this means was led to his dualism.

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* Here Professor Ostwald may think of Tycho Brahe.—Ed.

Now it is characteristic of modern energetics that it sets aside even this dualism and installs energy as the sole universal generalization. All phenomena are reduced to properties and relations of energy, and especially matter, in so far as such a concept would at all prove useful, is to be defined in terms of energetics.

The question why or for what purpose we should or must undertake this reversal of the significance of ideas, is answered by the fact that the concept of energy as a matter of experience is proved to be broader than that of matter. When this is once discerned all discussion will naturally cease. We can not define the concept "man" by the concept "negro" but we can do the reverse. The concept of light or electricity can not be defined by the concept of matter for the former are both recognized to be immaterial objects; but both can be defined by the concept of energy, for they are kinds or factors of energy, whence it may above all be deduced that the concept of energy is indeed broader than that of matter. That even matter may be given a definition from the standpoint of energetics, —yes, even that the only clear definition of matter is that provided by energetics, will be set forth later.

Above all the new element in Mayer's train of thought was so altogether new that its "mortal coil" so painful to bear remained unnoticed. On the contrary, the work of Mayer's contemporaries and immediate successors who with him were the first to comprehend the monstrous import of the new thought, tended to attach the new knowledge as closely as possible to the old traditional conceptions. Both Joule and Helmholtz advocated the mechanical theory of all natural phenomena. They saw in the transformations of energy nothing but the changes of atomistic motion, and especially Helmholtz sought an explanation for the law of the conservation of energy in the hypothesis that central forces, dependent merely on distance, were alone operative between the atoms.

In theoretical mechanics a special case of the law of conservation was known as the statement of the conservation of "living force," or momentum, which announced that when a celestial body reaches in its course a certain distance from its central body it possesses always the same velocity and therefore the same momentum or energy of motion, independent of the direction of the motion and the position of the point. In other words, if any sphere is placed around the central body of the system, the celestial body has always a definite value of its momentum when it finds itself anywhere in the plane of this sphere. The larger the radius of the sphere the smaller this momentum, and the function of distance (the potential) was also admitted which with the momentum yielded a constant difference (or a constant sum, according to the definition of the function in question).

If we so define the potential that its sum is constant with the momentum, we then have, as we know, the particular case of the law of the conservation of energy with regard to which only two kinds of energy (i. e., momentum or kinetic energy, and energy of position or distance) are to be considered, and are mutually transformed the one into the other. A condition of this relation is that no measurable part of energy is transferred to other forms in these motions. Especially in terrestrial processes the unavoidable conversion of a portion into heat is so infinitely small that it never comes into consideration in experiments. Its existence is accepted only on the ground of the principle of continuity, but has not been the object of a direct measurement. Whenever it occurs, it remains outside the limits of our present instruments of measurement.

By virtue of a general property of our thought according to which we conceive of new facts as analogous as possible to those already known, it would now be possible to look upon this well-known and, because of its simplicity, easily comprehended and transparent relation as the norm or type for all other kinds of transformation of energy. This could happen only on the assumption that no other kinds of energy exist in the world than those which have been seen to be active in the astronomical phenomena already described. To be sure, in heat, light, electricity, etc., a large number of other kinds of energy were already recognized which without further remark might be considered as energy of motion or of position. The hypothetical supposition remains, that even in these cases only the two kinds of energy above named were really to be found, but that the corresponding motions and attractions took place between the invisible and immeasurably small atoms.

By this hypothesis, to be sure, the above mentioned psychological requirement was satisfied in a very far-reaching way, for by its means the concept of energy was simply made a component part of the mechanistic world-conception which at that time was very wide spread, and according to which everything that happens is supposed in the last analysis to depend upon the mechanical interaction of atoms. It is true that Leibnitz had already raised the pertinent objection that such an explanation would not account for psychical phenomena. For if the whole category of motions of the hypothetical brain atoms accompanying a given thought process should in any way be made visible to us, we would see only tiny bodies in motion but not the corresponding thoughts, and the existence of the latter would remain as far from explanation as before. The weight of this objection meanwhile remained disregarded until a generation ago when Dubois Reymond raised it again and recognized it as an insurmountable barrier to the mechanistic world-conception. He was, to be sure, so convinced of the truth of the mechanistic view that he could not draw the conclusion that it was insufficient, but simply thought that here he would be compelled to note an absolute limit to the power of human intelligence. This attitude indicates the almost entirely undisputed dominion of the mechanistic conception (at least among naturalists) at the time of the discovery of the law of energy, and gives a psychological explanation for that arbitrary narrowing of the law of the conservation of energy which is now under consideration.

Another consequence of this same conception must be mentioned here, namely the division of all energy into kinetic and potential. It is directly evident that this division is one expression of the similar hypothesis that astronomical phenomena are typical for the whole category of natural phenomena. The extremely hypothetical character of this division is most obvious from the fact, for instance, that opinion is entirely divided as to whether the electric current represents kinetic or potential energy. On the ground of the kinetic hypothesis the kinetic nature of heat seems to be generally accepted, but if we ask for any objective sign by which kinetic energy is to be distinguished in these cases from potential, we receive no answer. Indeed I know of no place in literature in which this question has been even asked, much less answered. The peculiar nomenclature which originated with Rankine, even gives expression to the fact that only kinetic energy has claim to full actuality, and that energy of position is not energy properly so called, but something which may become energy only under certain circumstances. The logical consequence of this still continues in the contradictory combination of concepts in the term "latent" heat. If we reflect that this became necessary just because the law of the conservation of energy was still quite unknown at the end of the eighteenth century when Black introduced the term, and that the expression "latent heat" was only used to save, at least outwardly, the idea that heat can not simply disappear as it seems to do in the process of melting or conversion to steam, the result is really remarkable. The by-paths which that old thinker had to tread because the law of energy was unknown to him, were involuntarily retained after the necessity had passed with the discovery of the law of energy; for there is now no difficulty in seeing that heat must disappear when the corresponding amount of energy is used for a change of condition (i. e., melting or conversion to steam).

The error in thought which is expressed by the words "potential energy" is by no means harmless. It prevents the comprehension of other kinds of energy as just as actual as the energy of motion. This is apparently due to the very obvious fact that the motion of a body endowed with kinetic energy can be *seen,* and hence we are convinced of its presence without being obliged to consider any further demonstration. But we can *feel* the existence of heat energy, and *see* light, and hence it comes that we can bring all energy to act directly or indirectly upon some sense organs and so betray its existence. Indeed an energy which could not in some way influence our organs of sense would be permanently unknown to us, and so could not form any component part of our world-conception. Kinetic energy, therefore, is not more actual or real in any particular than any other kind of energy, and every energy which is transformed into another is potential with regard to that other, which is itself actual. This is the only consistent meaning which can be ascribed to these expressions, still science has shown no necessity for a short word by which to indicate the above mentioned relation, and therefore the best we can do is to drop those misleading terms entirely.

We are directly led by these observations to the general question as to the "real." If with every scientific precaution and by avoiding all tacit hypotheses, we try to characterize our relation to the "universe" (*Welt*), we can say that at the beginning of our conscious life we find ourselves brought into contact with a large number of experiences between which we can discover only a very slight connection. This is most distinctly expressed in the fact that we are able to foresee so little of what will take place in our future. For foresight is the peculiar content of our understanding; the measure of foresight according to space of time and multiplicity of foreseen events, is at once the measure of our intelligence. The new-born child foresees nothing except that he will find nourishment on the reaction upon certain irritations of smell and feeling (wherein it may remain a question whether consciousness is already active) and so stands upon a very low plane of intelligence, but even the highest grade of this attribute as it may be embodied in a successful investigator, politician, or captain of industry, is exactly characterized by the fact that such a man can foresee more and farther than his opponents or competitors.

We say that we know the things which we can foresee; we feel at home with regard to them, and their foreknown spatial and temporal relations are comprehensible to us. Upon such things, so far as sense-impressions are concerned, we at the same time bestow the name of "real" things. This expression is applicable only in so far as we are dealing with things of the so-called external world.

The "reality" of our thoughts is so self-evident to us that we give it no thought; we know that they form the primary component parts of all our conscious experiences. Dreams, hallucinations, and the like we call unreal external objects because they do not follow the rule which we have laid down according to our experience for "real" external objects, i. e., because the predictions are not usually fulfilled which we have applied to external objects from our experience with them. As soon, however, as such things are shown to be according to law and able to be foretold, they enter at once into the realm of reality. This is explained by the example of hypnotic phenomena which were considered as figments of the imagination by earlier critics and were cast aside as unreal, while to-day the character of reality is granted them through the knowledge of conditions upon which their occurrence depends and the special peculiarities with which they are regularly associated. It must still be observed that the expression "foretell" is not to be applied exclusively to those parts of a phenomenon which take place successively in time, but to those parts also which range next to each other in space. Moreover since we can not become aware of all these parts at the same time because they enter into consiousness one at a time, so to our experience each juxtaposition in space becomes also a succession in time. But space possesses the special peculiarity that this succession can enter our consciousness in arbitrary sequence if not exactly according to our choice.

In the light of these observations, it is obvious that there can be no question of unreal energy either of position or distance. If we know in general that a body above the surface of the earth can perform a definite amount of work while it approaches the surface, the sight of an elevated body affords us direct knowledge of ready energy with the same certainty as would the sight of a body in motion.

Accordingly from the standpoint of a profounder and more general contemplation of the concept of reality, the distinction between actual and potential energy becomes an untenable and even dangerous error.

How now do matters stand in regard to the reality of energy itself? Mayer, as above mentioned, has expressly asserted its reality, but his view has met with but little support. Although at one time men were very ready to recognize the justice and importance of the law of the conservation of energy, they have troubled themselves but little about the general viewpoints by which Mayer was led to his great generalization. We have previously seen that it was exactly his desire to work out the real, the substantial, in "forces," that led him to the train of thought which proved so rich in consequences. In contrast to this there are authors even in our own time, who substitute for the central significance of the concept of energy a certain anxiety to recognize energy as a substance right or wrong, and to ascribe to it at least the same degree of reality as to matter. We find again and again the statement that energy is merely an abstraction or mathematical function possessing only the particular attribute of retaining its value under all circumstances. This causes a confusion which is obvious from a special peculiarity of all European languages, and with regard to which one should be greatly on his guard since its frequent repetition shows how easily it can cause trouble. This is the linguistic custom of indicating .by the same word both the general concept and the concrete thing which corresponds to that concept.

By music, for instance, we understand the general art of so arranging tones that they create an esthetic impression, as well as each particular case in which this performance is put into practice. In the same way we call energy in general that function of measurable quantities which possesses the property of conservation under all circumstances, as well as each particular value of this function that has been observed in nature. Obviously those who refuse reality to energy have in mind the universal concept from which in the interest of its universality every superfluous particular manifestation is omitted. In so doing they overlook the fact that the word energy denotes at the same time the concrete realization of the universal function. If a thing exists which possesses a definite numerical value that can be expressed in producible units and which can not be changed by any known process it will fulfil in the highest degree all requirements that can be made of a reality. Especially does it make possible the prediction that one may count its value the same before as after a desired operation. What scientific and technical meaning this possibility of prediction possesses it is not necessary to explain, for upon this rests all of the enormous progress which has been brought about by the discovery of the law of the conservation of energy.

Finally the reality of energy results in the most evident way from the circumstance that it possesses a marketable and commercial value. This is most clearly shown in the case of electrical energy. Here energy is consumed and paid for by the consumer, while all "material" portions of electrical apparatus are neither diminished nor altered by its use.

The confusion thus mentioned finds some excuse in the circumstance that the general concept of energy is indeed exceptionally broad and comprehensive, and with relation to its particular charcteristics permits of an almost unlimited diversity. Besides the fact that energy is an essentially positive magnitude, possessing the character of magnitude in a narrower sense (i. e., it can be added to *ad libitum*), and further, besides its quantitative conservation in all possible transformations, I could indeed mention no characteristic which would be equally valid for all the different kinds of energy. This circumstance, however, has occasionally been made to count as a reason against energetics, just as if this universality were a fault or blemish of the energy-concept. Meanwhile we need reflect only a moment upon the problem to be solved in order to see that exactly this objectionable attribute is necessary for the desired purpose.

What then is the task before us? We must find a concept which is applicable to the greatest possible range of phenomena and offers the greatest possible amount of definite information about each particular case. The mechanistic philosophy sought this concept in motion, but was obliged to resort further to the concepts of mass and force in order to render possible the representation of actual phenomena; and the result for the non-mechanical (or in the sense of this hypothesis, crypto-mechanical) phenomena with reference to possible predictions was equal to zero. What conclusions had been drawn from the mechanistic hypothesis, for instance, that heat consisted of a motion of atoms? Nothing definite at all; for the kinetic hypothesis which Bernoulli evolved on the condition of gases rests upon a large number of other hypotheses, as is at once apparent from the fact that it has no application to liquid and solid states. With regard to the particular character of the supposed motions, the mechanistic hypothesis provided no direct information, and since these hypothetical motions had to have some magnitude and direction, many qnestions arose which had no empirical meaning, i. e., pseudo-problems (*Scheinprobleme*), to use a happy term of Mach's,—problems of such a remarkable character that even if their solution were made possible by some supernatural powers we would be unable to utilize it since it has no reference to observable magnitudes.

In contrast to this, the extraordinary universality of the concept of energy brings it about that such pseudo-problems never occur. If heat appears in any formation we can say nothing, to be sure, about the "inner nature" of this phenomenon on the strength of the principle of energy, but we can know in advance that all varieties of this heat will be parallel to corresponding variations of other similar energies whose amount we can calculate in advance from the amount of their heat variation. Further, from the particular property of heat-energy which is called temperature we can make other very characteristic predictions, but in so doing we are dealing always with measurable things and never with the unknown "heart of nature."*

This my opponents are ready to grant but they maintain that just herein lies the imperfection of energetics, while the mechanistic conceptions permit an invasion, although but hypothetical, into these mysteries. This logic is like that of a merchant who would place but little importance upon the careful computation of his assets and liabilities, and instead would set up a hypothetical account of how much property he would have under such and such circumstances. Even if he were to make his hypotheses plausible yet no one would call such an account reliable or business-like. He may reflect upon possibilities or probabilities in order to become clear about investment in an uncertain business, just as an investigator will speculate about the probability of the unknown conditions of a domain which he wishes to investigate, that he may have some idea in what direction to begin his experiments. But the reliable merchant, like the reliable man of research, will extend such forecasting of possibilities only to those conditions which he can and will afterwards submit to demonstration, and which will then have only measurable and verifiable things for objects. As soon, however, as he introduces inaccessible factors into his calculation his work ceases to be reliable. We must therefore distinguish carefully such experimental assumptions of unknown relations between accessible quantities, from the hypotheses about conditions of things merely thought of and therefore inaccessible. Only the latter kind of hypotheses needs to be discarded, while the first is a necessary element of research.

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* This translates Goethe's well-known expression *"das Innere der Natur."*—Tr.

In the scientific language of to-day these two fundamentally different kinds of hypotheses are called by the same name, "hypothesis." I am in favor of leaving the name hypothesis for the unverifiable assumptions, since indeed most hypotheses of the science of to-day are of this character. The other assumptions which, like a scaffolding, serve the purpose of the particular investigation on hand, and in the course of the work are replaced once or oftener according to our need by new usable assumptions until the condition sought for is actually found,—these assumptions made for the purpose of positive work, I call prototheses. A protothesis, therefore, is set up at the beginning of an investigation and disappears at its close if the work is successful; while a hypothesis is established when the work can be carried no farther. For this reason it is customary that in the production of scientific work the different prototheses which the investigator has employed are for the most part not mentioned at all, for it has been usual to communicate only those assumptions which the investigation has finally proved to be correct or at least approximate. Silence is kept with regard to the unsuccessful prototheses just as the scaffolding is removed after the building is completed. Only very rarely, as for instance in Kepler's reports of his astronomical researches, do we learn a little about the unsuccessful prototheses. On the other hand the hypotheses in the narrower sense occupy a large place in literature. Because inasmuch as they have reference to scientifically inaccessible things they can be neither proved nor refuted, an endless pro and con is the usual result; further, because among the problems there are also pseudo-problems which do not at all refer to demonstrable things, these problems are unsolvable and are dragged through science as unanswered questions which can not be disposed of, but not until they are recognized to be merely pseudo-problems.

It is therefore very important to have a sure method for the recognition of hypotheses in the narrower sense, and of pseudo-problems. Such a distinguishing mark has already been given in what we have just said, at least for the domain of the exact sciences. When expressions or notations of magnitudes which can not be observed and measured and for which we can substitute no definite and empirically determinable value, occur in a formula by means of which some physical relations are to be represented, we have to deal with an hypothesis. For the task of the exact sciences is to establish the reciprocal relation of measurable and demonstrable quantities, or in other words to find the mathematical forms or functions by which these quantities are interrelated, so that one of them can be calculated when the others are given. In order to establish experimentally such a functional relation it is therefore necessary to measure singly all variable or constant magnitudes which appear in such an equation. No other means is known by which to establish whether the protothetically assumed functional condition exists or not. As long as a single magnitude appears which is not susceptible to measurement, we can not consider the assumed condition as proven. Then, too, such an equation is useless, for since it expresses the condition of a magnitude which is not susceptible of measurement, it makes a statement about a thing which has no influence on, nor significance for, science or life. For not being susceptible to measurement is only another expression for the fact that nothing at all depends upon this thing. If anything did depend upon it this dependence would be one way to experience something about the thing, and it would be measurable.

This recipe for the discovery of pseudo-problems refers of course only to the relations of measurable quantities which can be expressed in mathematical equations. Not until our own time has mathematics reached the point where there are other generalizations besides quantities which permit of mathematical treatment, and the corresponding method of calculation has not yet been developed for general use. So by means of the still imperfect medium of the language we must attempt to solve the further problem of characterizing pseudo-problems in general. We shall find the way for this in an observation which has just been made. If the solution of a problem would change nothing in our conception of actual relations, it is characterized by this fact as a pseudo-problem. The recipe accordingly is as follows: Suppose the problem solved and assume any one of all possible answers to be correct, we then investigate what effect this would have on our conduct. If it produces no effect the problem is thereby indicated to be a pseudo-problem.

In order to learn the application of this prescription we may put the following question, Did the world have a beginning in time, or has it existed from all eternity? By way of experiment we will assume that it has existed since eternity, and will ask what would change in our conduct by this knowledge? I find at least for myself that nothing would change by this knowledge, and just as little if we assume that there was a beginning in time. Hence I must say that even if I positively learn in some way which of the two possibilities is correct, it would be a matter of perfect indifference to me, and this being the case we have here a pseudo-problem.

The significance of this procedure is apparent from the answer to the question as to what we call "correct" or "true." The answer was, that which enables us to make accurate predictions. Something which does not allow us to make any prediction whatever is essentially of no interest to us in any way, and there is no need of being concerned about it.

Now if we apply these observations to energetics we will recognize the fact that we can protect ourselves successfully against pseudo-problems by formulating our questions concerning phenomena from the viewpoint of energetics. At present it may be stated without fear of objection that among the different domains of physical phenomena there is no other universal condition than that of energy. That is to say, whatever may happen physically (chemical and physiological phenomena are here always included under this term) we can state an equation every time between the energies that have disappeared and those newly arrived. There is no other physical quantity to which such a generalization would apply. Further since such a statement refers always to measurable and demonstrable things on account of the general measurableness and demonstrability of energy, therefore all applications of the law of the conservation of energy treat of actual, and never of pseudo-problems. There are cases in which the exact measurement of energy magnitudes under discussion offers very considerable difficulties and on which therefore only gross approximations can be reached; but these can not invalidate the general principle. Just so there are very many cases of the law of conservation in which all members of the equation do not permit of measurement; such cases are to be considered asprototheses; that is, that in the case where we can not prove the conclusiveness of the law of conservation by a measurement of all the single members, we make the assumption that the law is conclusive, but we reserve to ourselves the right to submit this assumption to demonstration as soon as possible.

A good example of this kind of scientific progress is shown in the measurement of the physiological evolution of heat in animals and man. The old measurements of Despretz in the first half of the nineteenth century yielded results in opposition to the hypotheses of that day. It was exactly the deeper investigation of this problem which led both Robert Mayer and Helmholtz to the discovery of the law of the conservation of energy. Finally in our days the instruments of measurement have developed so far that the validity of the law has been proven with an exactness of 1:1000 even for physiological combustion (including mechanical and psychical work performed). As long as these latter measurements were not under consideration, the assumption of the validity of the law of conservation for physiological combustion was a protothesis which referred to things that were fundamentally measurable even though the technical accomplishment of measurement was so difficult that one could not place perfect confidence in it. Now it is a scientific truth that is involved, which, to be sure, possesses this quality only to the possibility of error in the ratio of 1:1000. That the law of conservation is also valid in this case is again a protothesis which awaits a demonstration in the future with more delicate instruments of precision.

To the question how the concept of energy in its great universality becomes capable of bringing to expression the infinite multiplicity of facts, the answer is that there are a large number of different kinds of energy, all of whose properties satisfy the above given definition with reference to the character of quantities, the essentially positive quality and the law of conservation, but at the same time contain still other additional qualifications or properties upon which their difference rests. Thus for instance, the pronounced binary character of electric and magnetic energy is altogether absent in heat, for this is perfectly determined by a mere number, the unit being given. Kinetic energy has a *direction in space* while volume-energy acts in every place and in all directions where a change in volume is made possible. Since nothing at all in the general concept of energy is stated about relations of space and time, these are available for narrower definitions and the variations here possible condition the variety of several forms of energy.

In this way is settled the oft repeated objection that the number of the different kinds of energy is extraordinarily large, and we must seriously consider the possibility of other kinds of energy as yet unknown. If energy is a concept that is serviceable for the representation of phenomena, then its variety must be representable by a corresponding variety of the concept. For all scientific subsuming and representation consists in coordinating to the varieties of the domain to be investigated another schematic variety of symbols (of a mathematical or linguistic nature), in which the corresponding functional relation is brought to expression. What enormous significance such a scientific sign-language has for the mastery of a domain, may be observed perhaps most plainly in the chemical formulas which provide a very considerable part of what universal facts science has been able to ascertain about chemical relations. Just as chemistry can not be blamed for its eighty elements since it is not at liberty to establish a number of its own choice, but is compelled instead to recognize as an element every substance which corresponds to the general definition, so energetics is not free to establish arbitrarily the number of its correlated kinds of energy but must carefully register the many kinds which present themselves and work out the characteristic indications of each particular species. The unity of this multiplicity becomes demonstrable and fundamental by virtue of the universal law of transformation.

A broader, more essential circumstance in this multiplicity, is the divisibility of all kinds of energy into two factors of characteristically general properties. For each kind of energy a factor of intensity is first determined which does not possess the simple quality of magnitude, i. e., is not directly addible; and in the second place a factor of capacity or quantity which is possessed of an unqualified addibility and which therefore is a magnitude in a narrower sense. The simplest way to conceive of this fundamental distinction is to unite physically two equal values of the kind in question. Two equal intensities will remain *unchanged* when joined together, but two equal capacities will yield a *double* result. If, for instance, two bodies of equal temperature or equal electrical potential are combined they remain unchanged and the temperature or potential, as the case may be, will be the same afterwards as before. Two equal masses, entropies, quantities of electricity, etc., on the other hand, when added together yield a double amount. Consequently, the former are intensities and the latter capacities.

Now, the values of these factors of energy bring a new multiplicity into the concept of energy which serves to express more important universal relations not touched upon in the law of conservation. A given quantity of heat for instance is always equivalent to a definite quantity of electrical energy whatever may be its temperature. Whenever one is transformed into the other the same amount is obtained. This indicates that the law of conservation is independent of the difference between magnitudes of intensity; there is an equal independence for magnitudes of capacity which appears from the fact that the product of the two produces the numerical value of energy. On the other hand the values of intensity are of decided importance for the question whether a transformation of energy will take place in a given case, and to what extent. These relations have become the best known with regard to heat. We know that a given amount of heat can be transformed into other kinds of energy only in so far as there is a difference in temperature. The unconvertible part is equal to the ratio of the available difference in temperature to the absolute temperature of the transition. But the same statement is valid also for all other kinds of energy. The pencil which I hold in my hand, by virtue of its motion through space which it shares with the earth and all that is upon it, possesses a kinetic energy which many times exceeds that of a discharged cannon ball; consequently it might originate the most incredible disturbances if it could only transfer its kinetic energy to other bodies. But this takes place only when there is a difference of velocity, and hence the enormous velocity which it possesses with reference to the sun's system of coordinates, is altogether unavailable in its terrestrial condition.

Accordingly while the first principle of energetics, or the law of the transformation of energy under the conservation of its numerical value yields an equation for every case where one energy becomes transformed into another, the second principle which governs the relations of intensity of energy, answers the question whether and when a transformation of existing energies would take place. Since two equal intensities do not influence each other (indeed the fact that they do not exert an influence defines the equality of the intensities) every transformation of any energies whatever presupposes some difference of intensity. On the other hand, since everything that happens may be characterized as a transformation of energy of some kind or other, the presence of difference in intensity is the general assumption of each occurrence.* When such a difference exists the amount of the occurrence, i. e., the amount of converted energy is proportional to the difference of intensity, and otherwise only dependent on the energies present and their factors. These considerations are collected together as a whole in the second principle of energetics, of which the part relating to heat was discovered by Sadi Carnot as early as 1827. In a more obvious, if not a more exhaustive, form this second principle may be stated with Clausius in the form "energy of rest is not converted of its own accord." Here energy of rest denotes that energy in which differences of intensity are not present and the compelling force by which it is converted lies in the introduction of new differences of intensity into the field under observation. More general is the form that in order for something to happen there must be no compensated differences of intensity, and the occurrence will be in proportion to these differences.

Naturally the question arises as to which rôle the magnitudes of capacity play in our world-conception of energetics. The answer is that in essential points the function of these is the same as that formerly ascribed to matter by the earlier yet undeveloped condition of science. If we consider that mass, weight, and volume, are kinds of energy corresponding to magnitudes of capacity we will again recognize these factors in the old "primary properties of matter." The "secondary" properties prove likewise to be magnitudes of capacity which however do not possess among themselves such close spatial relations as the above mentioned.

The peculiarity that the kinds of energy, volume-energy, gravity-energy, and motion, appear always united in space, has led to the concept of matter; but since the amount of these energies is itself variable in any such given formation it became necessary in order to give expression to this variability to assume a substratum for those variable properties which in itself would be without properties and therefore immutable. Thus arose the present logical malformation of the concept of matter as a thing that lies at the basis of all particular objects but itself has no properties by which it can be recognized and demonstrated.

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* This condition is indeed necessary, but not sufficient, for "compensated" differences of intensity may also exist without anything happening. These relations are also regulated by law, and we have only refrained from entering upon them in order that the presentation might not become needlessly complicated.

But though it is clear that no satisfactory description of the conditions of ponderable objects can be derived from the concept of matter, the question how it comes that those three kinds of energy are always found combined in the same space, still remains unanswered. The answer may be furnished by the investigation of the question as to what the condition of a formation would be if one of these energies were lacking. If there were no volume-energy then the object would take no room and therefore could not be either perceived or in any way manipulated by us. If there were no motion the object would have no mass and would consequently at the smallest impulse receive an infinite velocity and at once escape all notice. Finally if it had no energy of gravitation, it would not remain upon the earth and so likewise would disappear from our perception. The result is therefore that the combination of these three kinds of energy is necessary in order that the object can become an object of our preception, and that therefore only such formations of the system of energetics can come to our knowledge as contain these three kinds spatially combined with one another. Whether there are formations in which one or another of these kinds of energy is lacking we do not know and can not know, but since they can form no component part of our universe we can not possibly take them into consideration nor have we any reason to.

Thus we admit that a definite experience surely lies at the foundation of the concept of matter; but in the formation of this concept it found only an imperfect and awkward expression, and this is the reason why the continued use of the word "matter" has become unsuited to scientific language. The complex of the three kinds of energy is called "a body" in our present phraseology. It may now be easily understood that nothing would remain of a body if we would deprive it in thought of all its properties, i. e., the energies present within its space; for since the body is nothing but a complex of energies it disappears in thought if the components of the complex should be considered removed.

It can not be my task to demonstrate that physics as a whole (including chemistry and physiology) can be represented comprehensively and exhaustively as energetics. This will even be granted by my opponents; they call into question only the usefulness of such a presentation. But I think that I have demonstrated this clearly enough here and in my numerous text-books. The greater usefulness of the energetic presentation is apparent nowadays in a very characteristic way in physiology and biology. These two sciences have hitherto suffered greatly under the atomistic mechanics, which has filled them with a host of pseudo-problems. I need only recall the countless theories of heredity, all of which possess the typical attribute that they can neither be proved nor refuted, and which therefore have become an inexhaustible source of fruitless discussion. At present we are beginning to see frequently that by referring the problem to the principle of energetics all those pseudo-problems are removed and science at last is placed in the state where it may propose real questions and seek and find real answers to them.

To be sure energetics in its present form does not yet embrace all the multiplicity of detail the manifestation of which we meet in biological phenomena. The spatial and temporal modalities in the course of a transformation of energy, definite in kind and amount, are especially governed by laws like the Ohm law in which constants of material and form occur in great variety. The theory of these occurrences has been established by Fourier in his theory of the conduction of heat, but a recognized extension of these conditions is still a problem of the future and may be designated as the most important problem of energetics to-day. Biology has everywhere to do with determinations of this kind and in the introduction of corresponding concepts (as, e. g., Reinke's "dominants") there is a demand that such tasks be accomplished even though no way is pointed out for their performance. Such a way would appear only when some general property or common law could be predicated of these "dominants."

On the other hand, the application of energetics in the range of the different sciences is not yet by any means exhausted. As an example of such virgin ground which will bear the richest fruits as soon as it is put under cultivation, I here give at the conclusion of these expositions a sketch of the beginnings of civilization from the standpoint of energetics.

That which distinguishes men from animals we call culture. In its commonest interpretation it consists in the fact that man possesses a much more extensive control over his environment. In other words, he understands how to influence and guide natural events in such a way that they shall take a course which corresponds to his requirements and desires. This ability is not unlimited, but the progress of culture is characterized by the increase of man's dominion over his world. Now if all events are defined as transformations of energy as we have seen, their control becomes directly dependent upon the control of the relations of energy, and the history of civilization becomes the history of man's advancing control over energy.

In order to recognize how definitely the facts of this apparently very general observation take form in every single case, we will outline according to the theory of energetics the first evolution of man from his earlier brute condition. We are willing to look upon the use of tools as the first sign of culture in the aspiring human race. But a tool can be accurately defined as a means by which existing native energy is given a character according to some definite purpose. In other words, a tool is a transformer of energy, and the more perfectly it is fashioned to carry out this transformation, the more perfect a tool it is.

Staves, clubs and stones probably served as the first tools. The energy which primitive man (like the animals) first had at his disposal is the chemical energy of nourishment stored up in his muscles. There is a definite amount of this energy which could be actualized in a definite range determined for the position of each body by the length of the arms. Hence when a man took a staff in his hand he increased the radius of his muscular energy by the length of his staff, and was therefore able to apply it more usefully. By the use of a club he could accumulate his muscular energy in the form of kinetic energy and bring it into play with sudden force where the club alighted. By this means it was possible to perform work which could not have been accomplished by the unaided activity of his muscular energy in the form of pressure.

The discovery of throwing was a great step in advance in the line of useful conversion of energy. It united the two stages of progress just mentioned and extended them. The radius of efficiency of muscular energy was thereby greatly increased and at the same time an accumulation of force resulted from a summation of the impetus of the throw. The improvements following upon this consist in the selection or construction of a vehicle for the transmitted energy so as to provide on the one hand the greatest possible amount, and on the other hand the most exact direction. In bow and arrow we recognize a further development of this problem in which the muscular energy is temporarily transformed into the elastic or form-energy of the drawn bow, mainly in order to have the advantage of direction; while its adaptation in a cross-bow is intended to store up the greatest amount of energy that can be stored as long before the shot as is desired, and therefore serves the purpose better.

Another kind of transformation of energy relates to the concentration of energy in small surfaces, as edges and points; both bring it about that muscular work by virtue of the diminution of resistance in the surface, is able to exercise so much greater an intensity of pressure. A sharp and pointed tool separates and penetrates objects which would remain invulnerable to the fist or a stone.

By a systematic combination of these expedients new ones are brought into existence. Sword and spear unite the increased length of the arm-radius with the concentrated effectiveness of edge and point. With similar adaptation the objects which are thrown or shot result later in the javelin and pointed arrow.

All of these inventions bear upon the valuation of the primary energy which is supplied in human muscles. It was indeed a monstrous advance when other sources of energy were drawn upon for the purpose of the individual. On the one hand we may here consider similar physiological energies; the use of slaves and domestic animals for work indicates this step and indeed I consider it probable that the former was first attained. Next followed the adaptation of *inorganic* energies as well: fire and wind were made subservient to human needs. In this way we are led on the basis of the energetic view, by a continuous transition up to the most complicated manifestations of our own day.

A second series of corresponding considerations is associated with the provision of the chemical energy of nourishment, which as the first step of muscular energy is a necessary assumption for its generation and utilization. The accumulation of provisions for the times when they will not be directly procurable, results as is well known in the foundation of capital.

Finally *value* in general rests upon the transformation of energy. One and the same amount of energy measured numerically is of course not indifferent even for the events of nature which do not permit of valuation. On the contrary a given amount of energy is the more convertible the greater the differences of intensity with which it is affected with relation to its environment. The valuation of energy for man's purposes is determined in a similar, although somewhat more complicated way, by differences of intensity and the coefficients of transformation dependent on them. An amount of energy is in general the more valuable, the more completely it may be transformed for man's purposes. Thus a piece of coal and a piece of roasted meat may contain an equal amount of chemical energy (measured as total energy as well as free) while both have a very different value with regard to human purposes. This is because man can not utilize by means of his digestive apparatus the chemical energy of coal, but can that of meat.

This relation characterizes the general state of affairs. Nature offers us native energy: in the first place the energy of the sunbeam, in the second, the products of the transformation of this energy which have been formed without man's assistance. To transfer this native energy into such forms as are suited directly to the needs of mankind is the universal task of man in his relation to nature. By every transformation of this kind one part of the native energy is converted by the equalization of intensity (which in the last analysis always amounts to an equalization of temperature) into the unusable form of latent energy, and only a certain fraction of the original native energy serves its purpose. Every machine, every process, in fact every intelligent person who improves this coefficient of transformation is valuable, and the greater the improvement and the more important for mankind the kind of energy upon which the improvement is devoted, the more valuable he is.

This criterion of value is universal. It relates as well to the simplest expedient of daily life as to the loftiest manifestation of science and art. The application of this thought to the different domains of human activity would require a book, so we will let the matter rest with only this allusion, but the reader is urged to apply the principle to any concern in which he is especially interested and to convince himself whether and how it fulfils its purpose.

In all the preceding expositions we have not discussed the relation of *psychical* phenomena to energy. I have long since expressed my opinion that the whole of psychology is undergoing a fundamental advancement through the protothetical assumption of the existence of a psychical energy. This becomes particularly evident in the old problem as to how spirit and matter can operate together, which is recognized as a pseudo-problem and is therefore set aside. If on the one hand there is no fundamental reason to prevent us from comprehending psychical phenomena from the point of view of energetics, and on the other hand so-called matter is recognized as a particular combination of energies, then what was formerly accepted as a contrast in principle between the two realms completely disappears and the problem of the connection between body and spirit belongs to the same series as the problem of the connection between chemical and electrical energy wihch is treated in the theory of voltaic chains and has been solved up to a definite point.

WILHELM OSTWALD.

GROSSBOTHEN, Feb., 1907.